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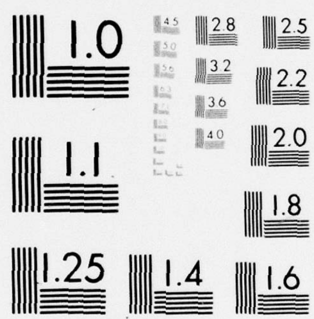

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TECHNICAL REPORT ARCLB-TR-77030

COMPUTERIZING THE EFFECT OF TEMPERING ON THE MECHANICAL PROPERTIES OF A Ni-Cr-Mo STEEL

Peter Dembowski

June 1977

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEM LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of an attempt to determine the optimum tempering cycle for gun tubes, mechanical properties of an AISI 4337 modified steel, i.e. gun steel, were determined for various tempering cycles. Austenitization temperatures of 845°C (1553°F) and 955°C (1750°F) were used, with tempering temperatures ranging from 425°C (797°F) to 595°C (1103°F) and tempering times ranging from 15 minutes to 240 minutes. This format, which allows the selection of tempering parameters from one plot to achieve desired properties, was developed. The mechanical property

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results for the material austenitized at 845°C are presented in the form of three dimensional plots and contour maps which interrelate the mechanical property of interest and tempering temperature and time. Examples showing the use of the plots are presented.

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INTRODUCTION

Heat treating of alloy steels has long been practiced using qualitative as well as some quantitative rules. An increasingly important aspect of heat treating is economical attainment of desired results. Rework, while never popular, carries increasingly heavy penalties in terms of wasted energy and labor. In scheduling of work, it would, therefore, be desirable to more precisely define expected results as a consequence of altering a procedure.

While some data for AISI 4337 modified exists in handbook form[1], and various reports in both the open and proprietary literature, very little data is found to cover a wide range of commercially desirable tempering conditions. Use of existing data was also limited since values for the range of interest are spread over a number of tables and figures in various reports. The usual procedure in presenting the effects of tempering is to plot or tabularize mechanical properties as a function of either temperature or time. It is necessary then, to try to determine the optimum tempering conditions, by interpreting and mentally interrelating the separate data.

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1. Aerospace Structural Metals Handbook, Ed, by J. Wolf, Mech. Prop. Data Center, Belfour Stulen, Inc., Traverse City, Mich. 1975.

To promote a more useable system, an interactive graphics system[2] was chosen as the vehicle for data presentation. By mapping levels of mechanical properties, and comparing expected results to those required by specification or a production order, time at temperature and processing temperature can be arrived at easily.

The key to this approach is to first display the three dimensional plot of the data set being considered. This orients the user to rapidly locate "geographic" features such as peaks, valleys, and plateaus which represent maxima and minima in the data. A good visualization of the topography of the surface will be an aid in interpreting the working diagram - the contour map.

Contour maps of mechanical properties can be read in the same way as geographic contour maps. Each contour line defines a particular value for the parameter being considered. For example, a contour line may indicate a specific yield strength or impact energy level. Every time-temperature tempering cycle indicated by the line will develop the specified mechanical property. Lines spaced closely together indicate a rapid change (i.e., a steep slope), while a large spacing indicates little difference

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2. Lorensen, W. "An Interactive Graphics Finite Element System", Structural Mechanics Computer Programs, Ed. by W. Pilkey, University Press, Virginia, pp 991-1001, 1974.

in values, or a plateau. Saddle points (whose topographic analogy would be ridge lines or valleys) are typified by "U" or "V" shaped bulges in contour lines.

This report deals with the graphical techniques developed. The specific use of the data for application to gun tube heat treatment will be separately reported.

EXPERIMENTAL PROCEDURE

Material used in generating the data set was taken from an 18" diameter hollow rotary forging which was air cooled after the forging operation. The composition of the material which was produced by the vacuum degassing technique, given below:

C	Mn	Si	Ni	Cr	Mo	V	P	S
.33	.62	.15	2.69	1.08	.53	.10	.009	.007

Discs, approximately 25mm thick and perpendicular to the longitudinal axis of the forging, were cut into blanks which were then heat treated. All blanks to be tempered at a particular temperature were austenitized together. Specimens were soaked at the austenitizing temperature for one hour. Times at temperature were measured after the furnace recovered its set point. Blanks were water quenched after austenitization and after tempering.

Two 8.75mm (0.350 in.) diameter tensile specimens and two Charpy impact specimens machined per ASTM standards were cut from each blank after heat treatment. Hardness (Rc) measurements reported were the average of five readings

taken on the unbroken ends of the Charpy bars after testing. Reported test results were converted to SI values using conversion factors given by ASTM E380-74.

RESULTS AND DISCUSSION

Test data collected for specimens austenitized at 845°C are presented in Table 1. Plots of the data set for 845°C austenitization are shown in Figs. 1a-6a, with the corresponding contour plots shown in Figs. 1b-6b. Limits of the axes are given in the legend at the left of the corresponding plot. Contour levels are plotted in ascending order.

The perspective plots (Figs. 1a-6a) are three dimensional analyses showing the effect of tempering temperature and times on a specific mechanical property. The legend to the right provides directions to the computer for plotting the data. The legend to the left deals with the limits of the parameters plotted and shows the orientation of the plot from the viewer's vantage point. The vantage point was selected to allow easy visualization of the plot. In these figures, X represents the temperature, Y represents the time and Z represents the mechanical property. The lines in the Y-direction represent constant temperatures, while those in the X-direction represent constant times.

The contour plots (Figs. 1b-6b) are two dimensional

plots of time vs. temperature for constant values of the mechanical property. They are derived from the perspective plots. Again, the legend to the right shows instructions to the computer. The legend to the left shows the value of the various levels plotted. These graphs can be used to determine time-temperature relations to achieve a certain property. For example, from Figure 5b, each combination of time and temperature determined from the line for level 3 will develop 25.0 Joules (18.4 ft-lbs) in impact energy. The Plots can also be used to determine the mechanical property which can be expected from a specific combination of time and temperature. For example, from Figure 5b, tempering at 560°C for 6000 seconds will develop approximately 30.0 Joules (22.1 ft-lbs) (level 4).

For choosing processing conditions, an overlay can be constructed by tracing a default level onto a transparent medium such as an acetate sheet. By placing this sheet on top of a map of a second property, regions of heat treating parameter combinations can be found which will give the desired tempering times and temperatures resulting in values of properties required in the product. The advantage of such a display is that contours of a desired level can be easily specified and located. Once a particular combination is chosen, estimates of a complete range of mechanical properties can be made.

Table 1. Tensile mechanical properties - 845C Austenitization

SPECIMEN NUMBER	AUSTENITIZING TEMPERATURE (C)	AUSTENITIZING TIME (SEC)	TEMPERING TEMPERATURE (C)	TEMPERING TIME (SEC)	0.1% YIELD STRENGTH (MPA)	ULTIMATE TENSILE STRENGTH (MPA)	ELONGATION %	REDUCTION IN AREA %	CHARPY IMPACT ENERGY (J)	IMPACT TEST TEMP (C)	HARDNESS (RC)
9P1	843.	3600.	482.	900.	0.1281E 04	0.1523E 04	12.1	41.2	0.2169E 02	-40.	43.0
9P2	843.	3600.	482.	900.	0.1287E 04	0.1529E 04	12.1	43.6	0.1627E 02	-40.	46.0
9T1	843.	3600.	482.	1800.	0.1243E 04	0.1428E 04	12.8	49.8	0.1695E 02	-40.	44.0
9T2	843.	3600.	482.	1800.	0.1240E 04	0.1426E 04	12.8	43.6	0.1695E 02	-40.	43.5
9H1	843.	3600.	482.	2700.	0.1233E 04	0.1401E 04	13.6	46.2	0.1763E 02	-40.	43.0
9H2	843.	3600.	482.	2700.	0.1222E 04	0.1399E 04	12.6	41.6	0.1763E 02	-40.	43.5
9V1	843.	3600.	482.	3600.	0.1225E 04	0.1393E 04	12.8	42.4	0.2237E 02	-40.	44.0
9V2	843.	3600.	482.	3600.	0.1236E 04	0.1384E 04	12.1	41.2	0.2237E 02	-40.	42.5
9F1	843.	3600.	482.	5400.	0.1207E 04	0.1372E 04	13.6	47.4	0.1627E 02	-40.	45.0
9F2	843.	3600.	482.	5400.	0.1225E 04	0.1391E 04	13.6	46.6	0.2169E 02	-40.	42.0
9G1	843.	3600.	482.	7200.	0.1219E 04	0.1380E 04	12.8	43.6	0.1763E 02	-40.	42.5
9G2	843.	3600.	482.	7200.	0.1229E 04	0.1374E 04	12.8	39.8	0.1898E 02	-40.	43.0
9X1	843.	3600.	482.	9000.	0.1207E 04	0.1372E 04	12.8	47.4	0.2102E 02	-40.	43.5
9X2	843.	3600.	482.	9000.	0.1200E 04	0.1364E 04	11.5	38.5	0.2034E 02	-40.	43.0
9Y1	843.	3600.	482.	10800.	0.1219E 04	0.1376E 04	12.6	44.9	0.1763E 02	-40.	44.0
9Y2	843.	3600.	482.	10800.	0.1205E 04	0.1368E 04	12.8	43.3	0.1898E 02	-40.	43.0
9S1	843.	3600.	482.	12600.	0.1213E 04	0.1372E 04	13.6	44.1	0.1898E 02	-40.	43.0
9S2	843.	3600.	482.	12600.	0.1211E 04	0.1368E 04	12.8	42.4	0.2237E 02	-40.	40.0
9K1	843.	3600.	482.	14400.	0.1209E 04	0.1372E 04	13.6	43.6	0.1695E 02	-40.	43.0
9K2	843.	3600.	482.	14400.	0.1211E 04	0.1377E 04	13.6	41.6	0.1763E 02	-40.	42.0
0D1	843.	3600.	538.	900.	0.1221E 04	0.1405E 04	12.1	31.8	0.1966E 02	-40.	44.0
0D2	843.	3600.	538.	900.	0.1229E 04	0.1411E 04	12.8	49.0	0.2034E 02	-40.	44.5
0P1	843.	3600.	538.	1800.	0.1198E 04	0.1353E 04	15.0	46.2	0.2169E 02	-40.	42.0
0P2	843.	3600.	538.	1800.	0.1188E 04	0.1351E 04	12.8	43.6	0.2576E 02	-40.	43.5
0E1	843.	3600.	538.	2700.	0.1186E 04	0.1347E 04	13.6	38.5	0.2440E 02	-40.	43.0
0E2	843.	3600.	538.	2700.	0.1198E 04	0.1360E 04	15.0	47.8	0.2169E 02	-40.	43.5
0Z1	843.	3600.	538.	3720.	0.1194E 04	0.1353E 04	15.0	41.6	0.2440E 02	-40.	41.0
0Z2	843.	3600.	538.	3720.	0.1178E 04	0.1345E 04	15.0	44.1	0.2440E 02	-40.	41.5
0K1	843.	3600.	538.	5400.	0.1178E 04	0.1347E 04	15.0	44.6	0.2169E 02	-40.	43.0
0K2	843.	3600.	538.	5400.	0.1188E 04	0.1358E 04	15.7	50.2	0.1966E 02	-40.	42.5
0G1	843.	3600.	538.	7200.	0.1180E 04	0.1345E 04	14.3	43.6	0.2102E 02	-40.	43.0
0G2	843.	3600.	538.	7200.	0.1192E 04	0.1347E 04	15.0	51.7	0.2440E 02	-40.	43.0
0C1	843.	3600.	538.	9000.	0.1180E 04	0.1358E 04	15.0	44.9	0.2576E 02	-40.	43.5
0C2	843.	3600.	538.	9000.	0.1183E 04	0.1343E 04	15.0	46.6	0.2576E 02	-40.	43.0
0M1	843.	3600.	538.	10800.	0.1178E 04	0.1343E 04	14.3	45.8	0.2779E 02	-40.	43.0
0M2	843.	3600.	538.	10800.	0.1182E 04	0.1340E 04	14.3	45.4	0.2712E 02	-40.	43.[illegible]
0Y1	843.	3600.	538.	12600.	0.1198E 04	0.1349E 04	15.7	50.2	0.2779E 02	-40.	42.5
0Y2	843.	3600.	538.	12600.	0.1173E 04	0.1343E 04	15.7	48.6	0.2712E 02	-40.	42.0
0X1	843.	3600.	538.	14400.	0.1184E 04	0.1353E 04	15.7	43.6	0.2847E 02	-40.	41.8
0X2	843.	3600.	538.	14400.	0.1178E 04	0.1343E 04	15.7	45.4	0.2576E 02	-40.	43.0
50K1	843.	3600.	566.	930.	0.1200E 04	0.1360E 04	15.7	51.0	0.2712E 02	-40.	43.0
50K2	843.	3600.	566.	930.	0.1192E 04	0.1350E 04	13.6	42.8	0.2644E 02	-40.	43.0
50X1	843.	3600.	566.	1800.	0.1163E 04	0.1333E 04	14.3	47.8	0.2983E 02	-40.	43.0
50X2	843.	3600.	566.	1800.	0.1182E 04	0.1343E 04	15.7	46.2	0.2576E 02	-40.	43.[illegible]
50E1	843.	3600.	566.	2700.	0.1167E 04	0.1340E 04	16.4	47.0	0.2644E 02	-40.	43.0
50E2	843.	3600.	566.	2700.	0.1180E 04	0.1340E 04	16.4	52.1	0.2644E 02	-40.	43.0
50G1	843.	3600.	566.	3690.	0.1145E 04	0.1319E 04	16.4	51.0	0.2983E 02	-40.	43.0
50G2	843.	3600.	566.	3690.	0.1171E 04	0.1333E 04	16.4	48.6	0.2983E 02	-40.	43.0
50Y1	843.	3600.	566.	5400.	0.1159E 04	0.1302E 04	16.4	47.8	0.3118E 02	-40.	42.0
50Y2	843.	3600.	566.	5400.	0.1157E 04	0.1307E 04	16.4	47.2	0.3525E 02	-40.	43.0
50P1	843.	[illegible]	[illegible]	7200.	0.1157E 04	[illegible]	15.7	[illegible]	[illegible]	[illegible]	43.5

Table 1. (Cont)

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SPECIMEN NUMBER	AUSTENITIZING TEMPERATURE (C)	AUSTENITIZING TIME (SEC)	TEMPERING TEMPERATURE (C)	TEMPERING TIME (SEC)	0.1% YIELD STRENGTH (MPA)	ULTIMATE TENSILE STRENGTH (MPA)	ELONGATION %	REDUCTION IN AREA %	CHARPY IMPACT ENERGY (J)	IMPACT TEST TEMP (C)	HARDNESS (RC)
50P2	843.	3600.	566.	7200.	0.1165E 04	0.1324E 04	16.4	52.5	0.3525E 02	-40.	42.5
50Q1	843.	3600.	566.	7000.	0.1140E 04	0.1321E 04	16.4	47.8	0.2983E 02	-40.	42.[illegible]
50Q2	843.	3600.	566.	9000.	0.1138E 04	0.1318E 04	16.4	49.4	0.2915E 02	-40.	42.[illegible]
50C1	843.	3600.	566.	11100.	0.1178E 04	0.1335E 04	15.0	44.6	0.3118E 02	-40.	42.5
50C2	843.	3600.	566.	11100.	0.1178E 04	0.1318E 04	17.1	62.0	0.3118E 02	-40.	42.5
50M1	843.	3600.	566.	13140.	0.1130E 04	0.1302E 04	15.7	47.4	0.3186E 02	-40.	42.5
50M2	843.	3600.	566.	13140.	0.1153E 04	0.1306E 04	15.7	47.8	0.3051E 02	-40.	42.[illegible]
50Z1	843.	3600.	566.	14400.	0.1140E 04	0.1303E 04	15.7	49.0	0.3254E 02	-40.	42.[illegible]
50Z2	843.	3600.	566.	14400.	0.1132E 04	0.1302E 04	15.7	51.7	0.2776E 02	-40.	41.5
100W1	843.	3600.	593.	900.	0.1186E 04	0.1343E 04	14.3	45.4	0.2335E 02	-40.	41.0
100W2	843.	3600.	593.	900.	0.1171E 04	0.1333E 04	14.3	44.1	0.2712E 02	-40.	[illegible]
100Z1	843.	3600.	593.	1800.	0.1154E 04	0.1312E 04	14.3	49.0	0.3390E 02	-40.	43.0
100Z2	843.	3600.	593.	1800.	0.1157E 04	0.1318E 04	14.3	47.0	0.3322E 02	-40.	42.0
100Q1	843.	3600.	593.	2700.	0.1163E 04	0.1319E 04	16.4	47.8	0.3186E 02	-40.	42.5
100Q2	843.	3600.	593.	2700.	0.1180E 04	0.1314E 04	16.4	47.0	0.3118E 02	-40.	42.0
100K1	843.	3600.	593.	3600.	0.1153E 04	0.1309E 04	16.4	47.8	0.3254E 02	-40.	42.8
100K2	843.	3600.	593.	3600.	0.1157E 04	0.1307E 04	16.4	47.8	0.3776E 02	-40.	42.0
100X1	843.	3600.	593.	5400.	0.1126E 04	0.1285E 04	14.3	47.4	0.4067E 02	-40.	41.[illegible]
100X2	843.	3600.	593.	5400.	0.1132E 04	0.1281E 04	14.3	49.8	0.3728E 02	-40.	41.[illegible]
100P1	843.	3600.	593.	7200.	0.1141E 04	0.1281E 04	15.7	49.0	0.3390E 02	-40.	[illegible]
100P2	843.	3600.	593.	7200.	0.1130E 04	0.1279E 04	16.4	47.4	0.3254E 02	-40.	41.[illegible]
100M1	843.	3600.	593.	9000.	0.1095E 04	0.1260E 04	15.7	49.8	0.4067E 02	-40.	[illegible]
100M2	843.	3600.	593.	9000.	0.1126E 04	0.1267E 04	15.7	50.6	0.4067E 02	-40.	41.5
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[illegible]	843.	3600.	593.	10800.	0.1134E 04	0.1281E 04	16.4	53.6	0.4339E 02	-40.	41.[illegible]
100Y1	843.	3600.	593.	12600.	0.1099E 04	0.1244E 04	14.3	52.1	0.4203E 02	-40.	41.[illegible]
100Y2	843.	3600.	593.	12600.	0.1101E 04	0.1240E 04	15.7	51.0	0.4067E 02	-40.	41.[illegible]
100C1	843.	3600.	593.	14400.	0.1122E 04	0.1253E 04	16.4	54.8	0.4881E 02	-40.	[illegible]
100C2	843.	3600.	593.	14400.	0.1103E 04	0.1240E 04	15.7	47.0	0.4831E 02	-40.	[illegible]
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12D2	843.	3600.	649.	1800.	0.1122E 04	0.1122E 04	17.1	53.6	0.4881E 02	-40.	[illegible]
12P1	843.	3600.	649.	2700.	0.1074E 04	0.1074E 04	17.9	56.8	0.5966E 02	-40.	[illegible]
12P2	843.	3600.	649.	2700.	0.1066E 04	0.1066E 04	17.1	51.0	0.5966E 02	-40.	37.[illegible]
12M1	843.	3600.	649.	3600.	0.1034E 04	0.1029E 04	18.6	54.8	0.5664E 02	-40.	36.[illegible]
12M2	843.	3600.	649.	3600.	0.1027E 04	0.1027E 04	17.9	51.0	0.6440E 02	-40.	37.[illegible]
12F1	843.	3600.	649.	5400.	0.9839E 03	0.9839E 03	18.6	54.8	0.7050E 02	-40.	[illegible]
12F2	843.	3600.	649.	5400.	0.9653E 03	0.9653E 03	18.6	54.8	0.6915E 02	-40.	[illegible]
12Y1	843.	3600.	649.	7200.	0.9611E 03	0.9611E 03	19.3	59.2	0.7728E 02	-40.	33.[illegible]
12Y2	843.	3600.	649.	7200.	0.9466E 03	0.9466E 03	17.1	50.2	0.7254E 02	-40.	33.[illegible]
12S1	843.	3600.	649.	9120.	0.9301E 03	0.9301E 03	18.6	60.0	0.7739E 02	-40.	33.[illegible]
12S2	843.	3600.	649.	9120.	0.9094E 03	0.9094E 03	18.6	59.1	0.7437E 02	-40.	33.[illegible]
12W1	843.	3600.	649.	10800.	0.9198E 03	0.9198E 03	18.6	61.2	0.7457E 02	-40.	33.[illegible]
12W2	843.	3600.	649.	10800.	0.9177E 03	0.9177E 03	18.6	54.8	0.7796E 02	-40.	[illegible]
12T1	843.	3600.	649.	12540.	0.8887E 03	0.8887E 03	18.6	56.8	0.7660E 02	-40.	30.[illegible]
12T2	843.	3600.	649.	12540.	0.8747E 03	[illegible]	18.6	59.2	0.7728E 02	-40.	[illegible]
12X1	843.	3600.	649.	14400.	0.8674E 03	0.8674E 03	18.6	54.8	0.7864E 02	-40.	30.0
12X2	843.	3600.	649.	14400.	0.8736E 03	0.1020E 04	18.6	50.2	0.7603E 02	-40.	41.[illegible]

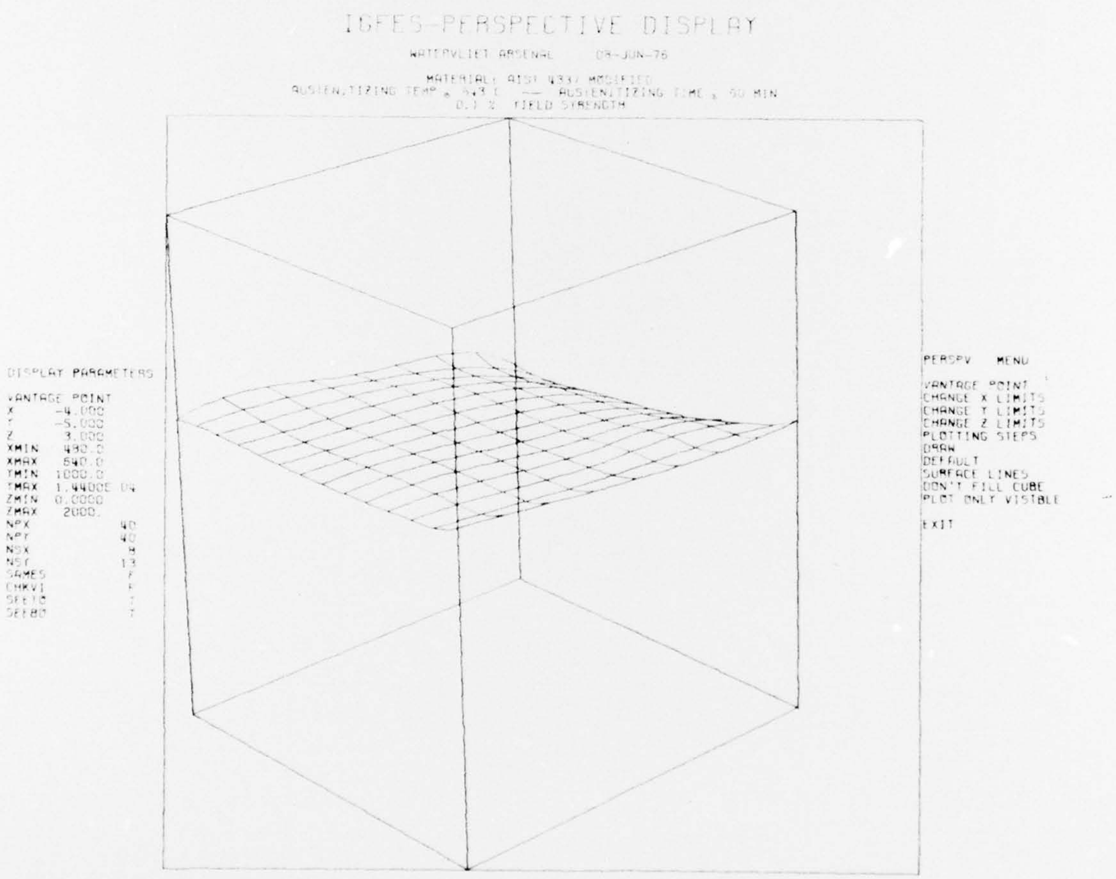

FIG. 1a. Perspective plot of yield strength.

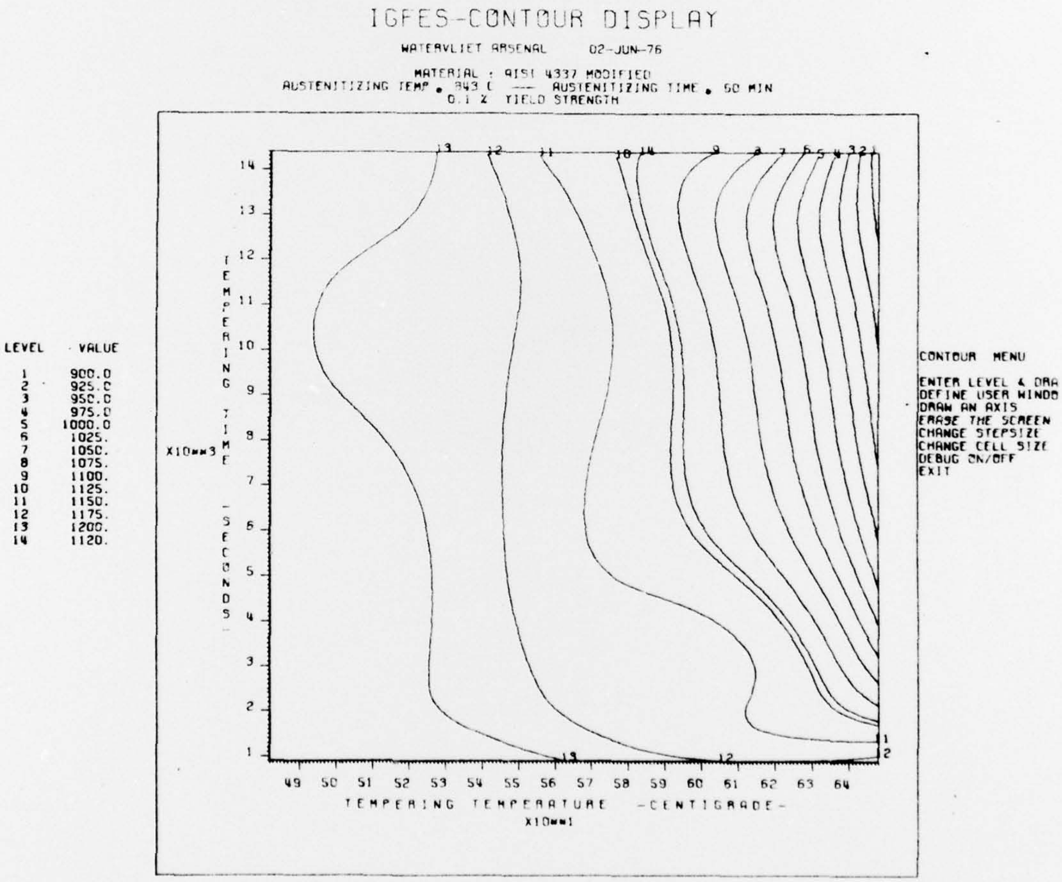

FIG. 1b. Contour plot of yield strength

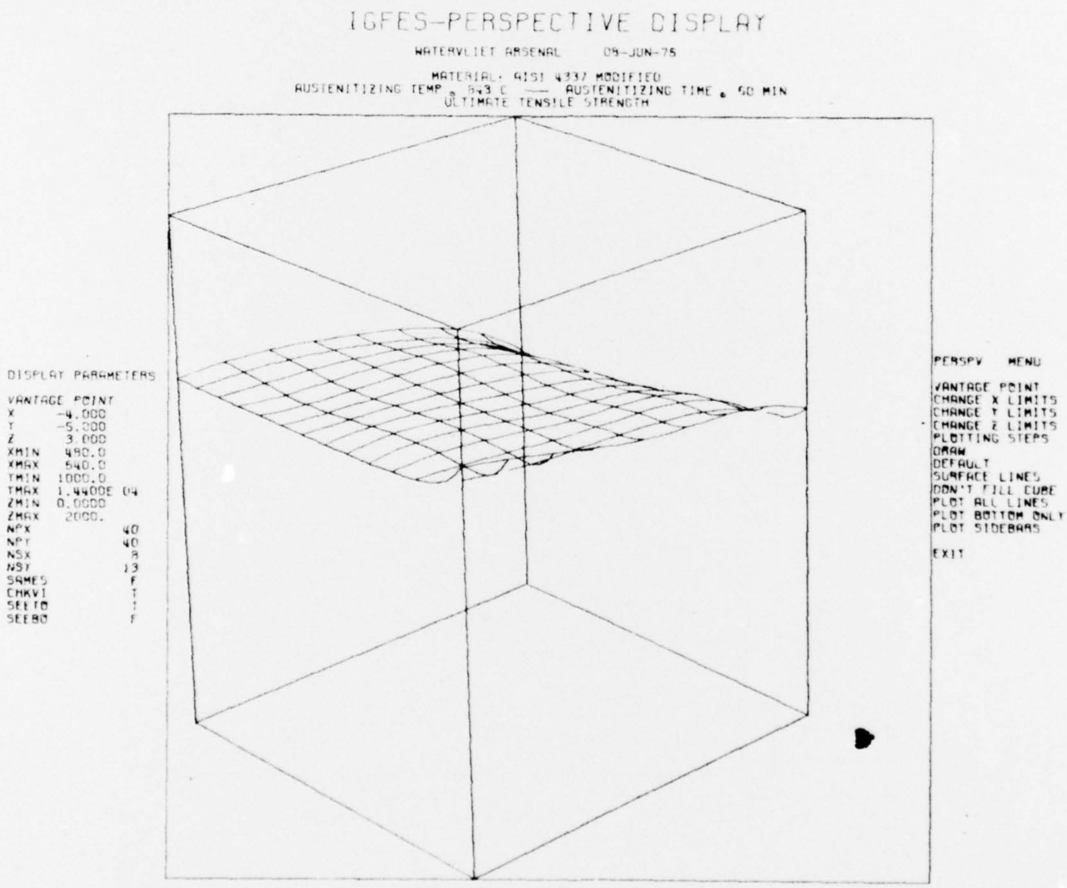

FIG. 2a - Perspective plot of ultimate tensile strength

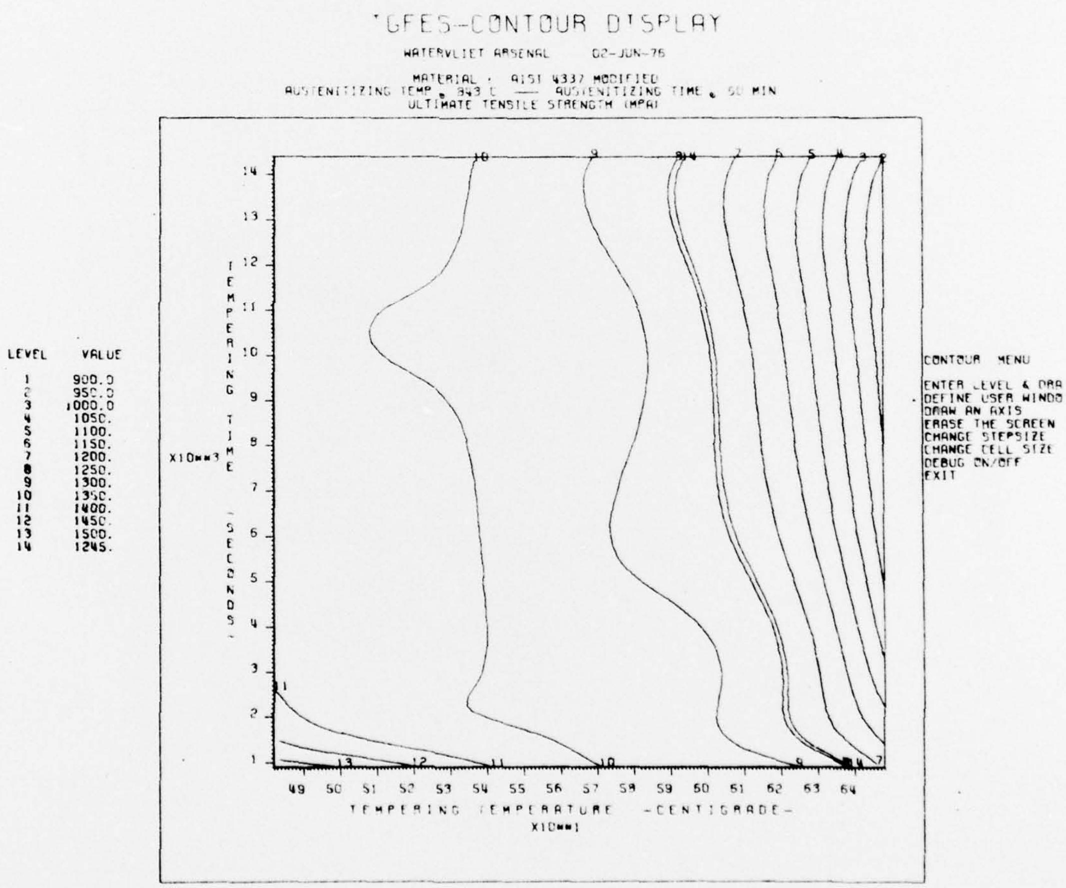

FIG. 2b Contour plot of ultimate tensile strength

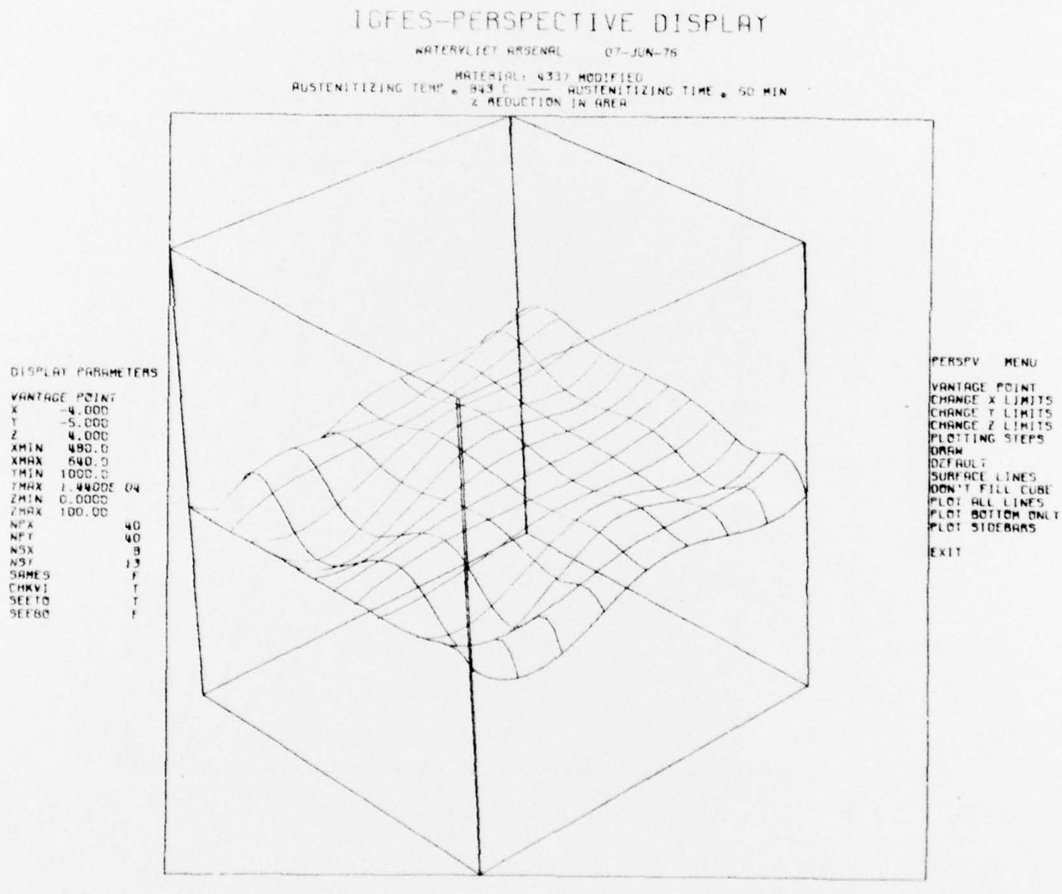

FIG. 3a Perspective plot of % reduction in area

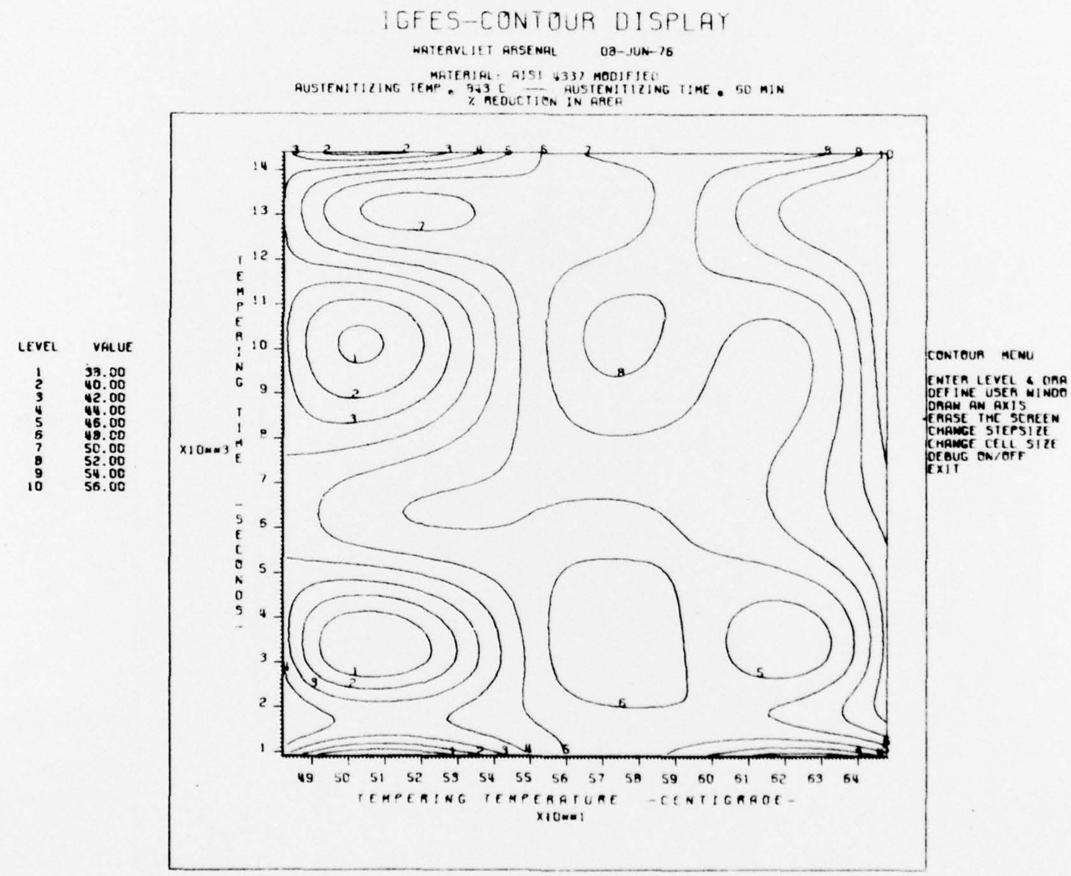

FIG. 3b Contour plot of % reduction in area

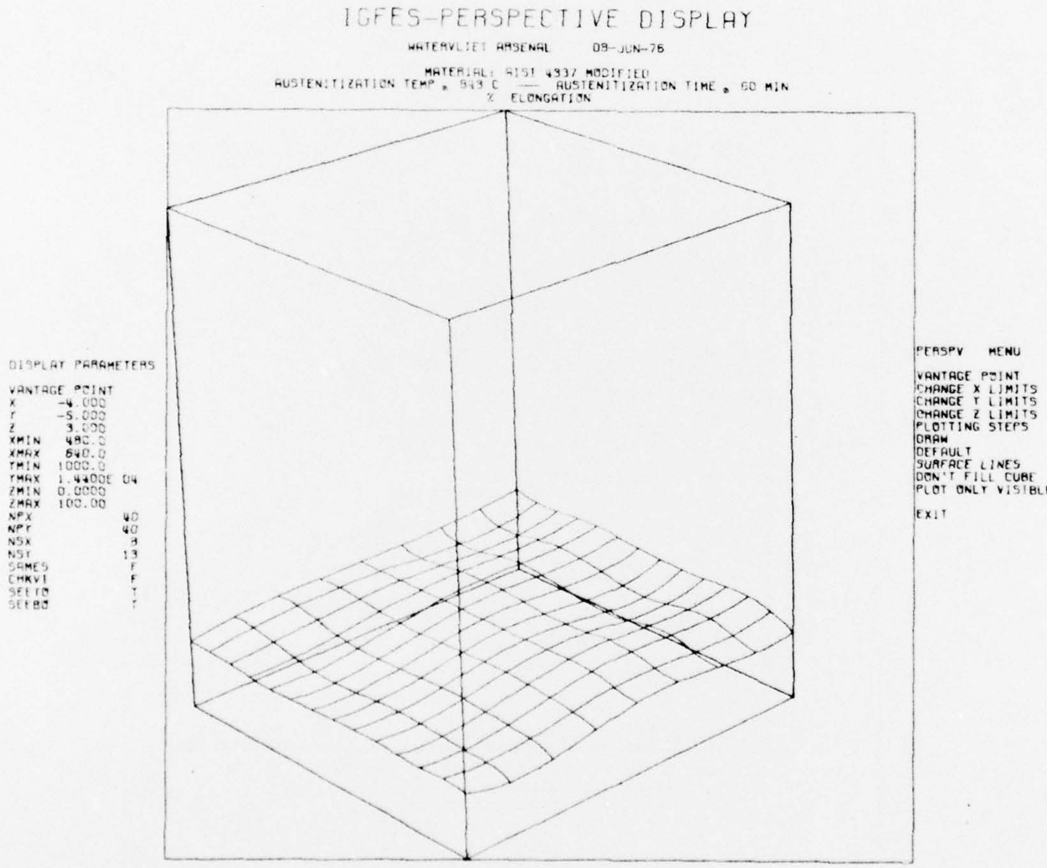

FIG. 4a Perspective plot of % elongation

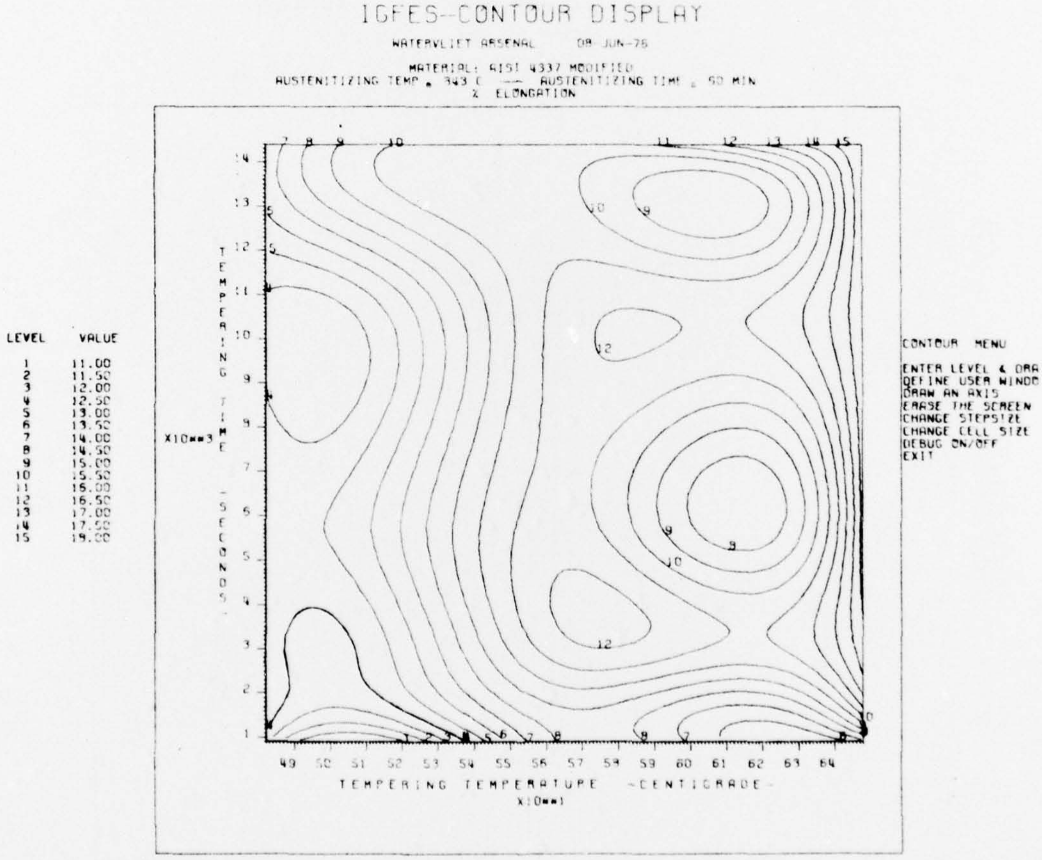

FIG. 4b Contour plot of % elongation

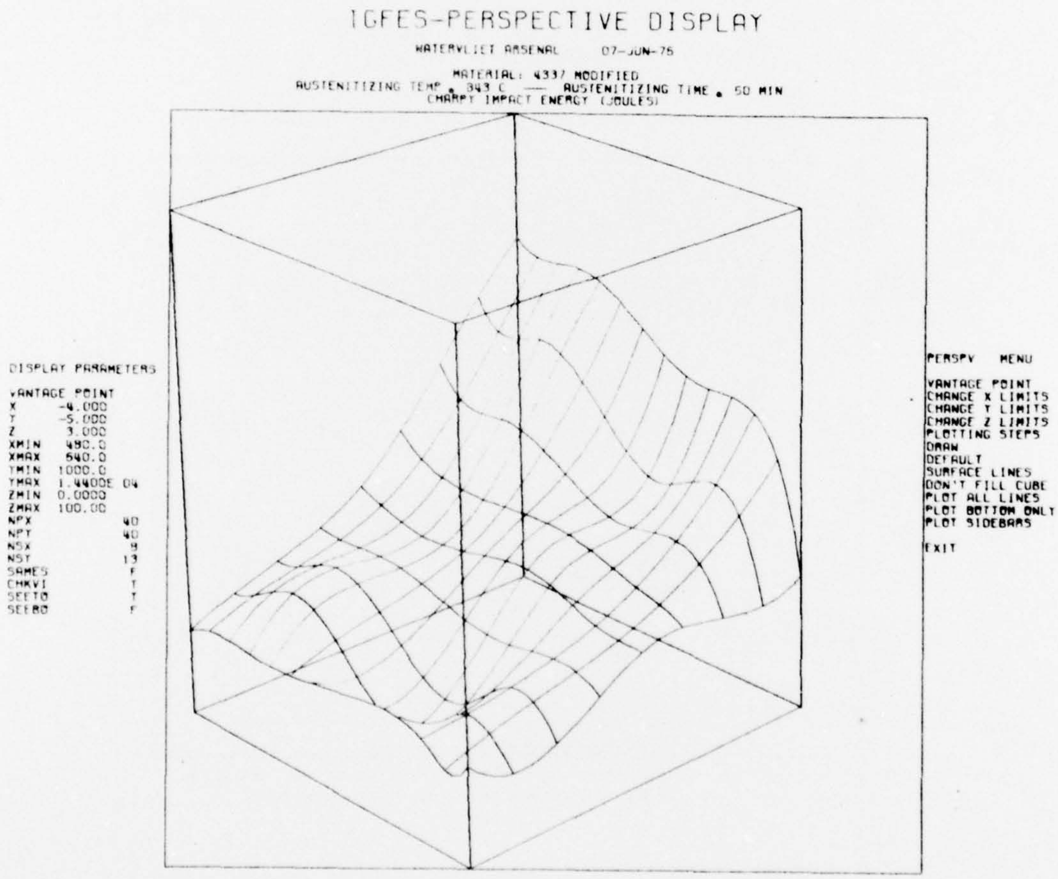

FIG. 5a Perspective plot of Charpy impact energy

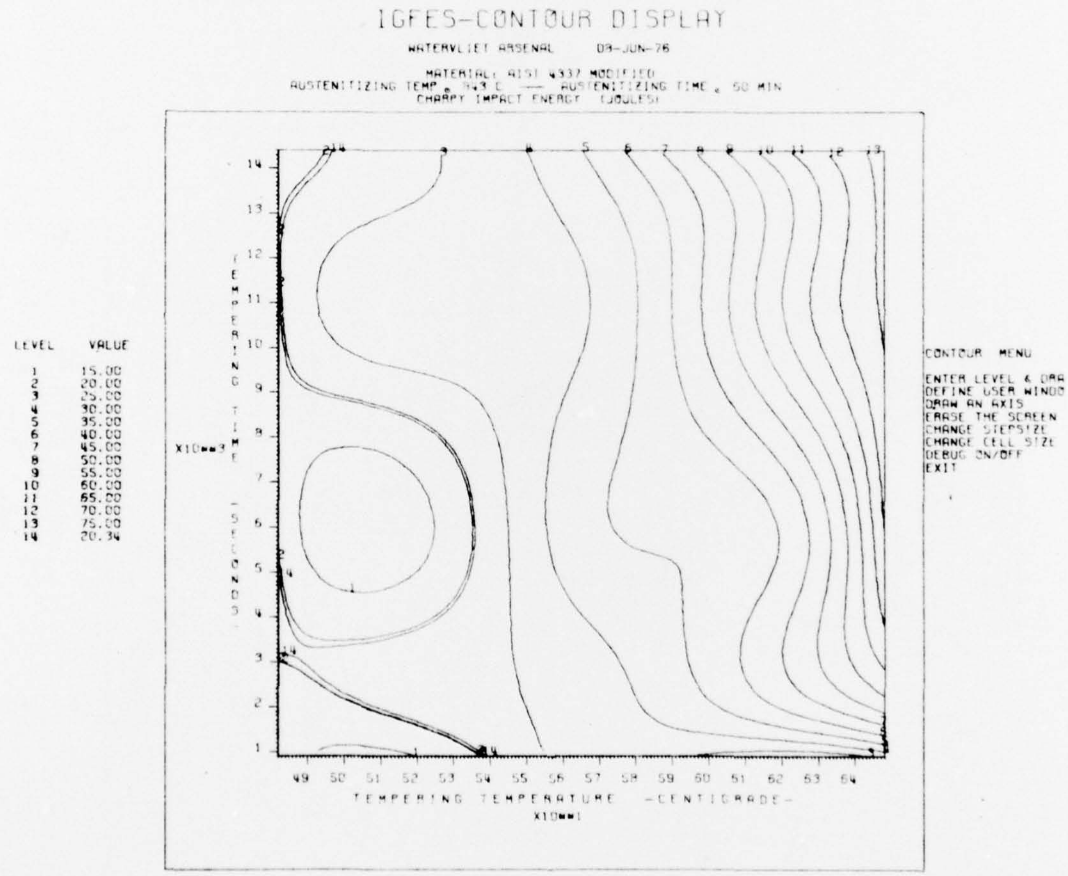

FIG. 5b Contour plot of Charpy impact energy

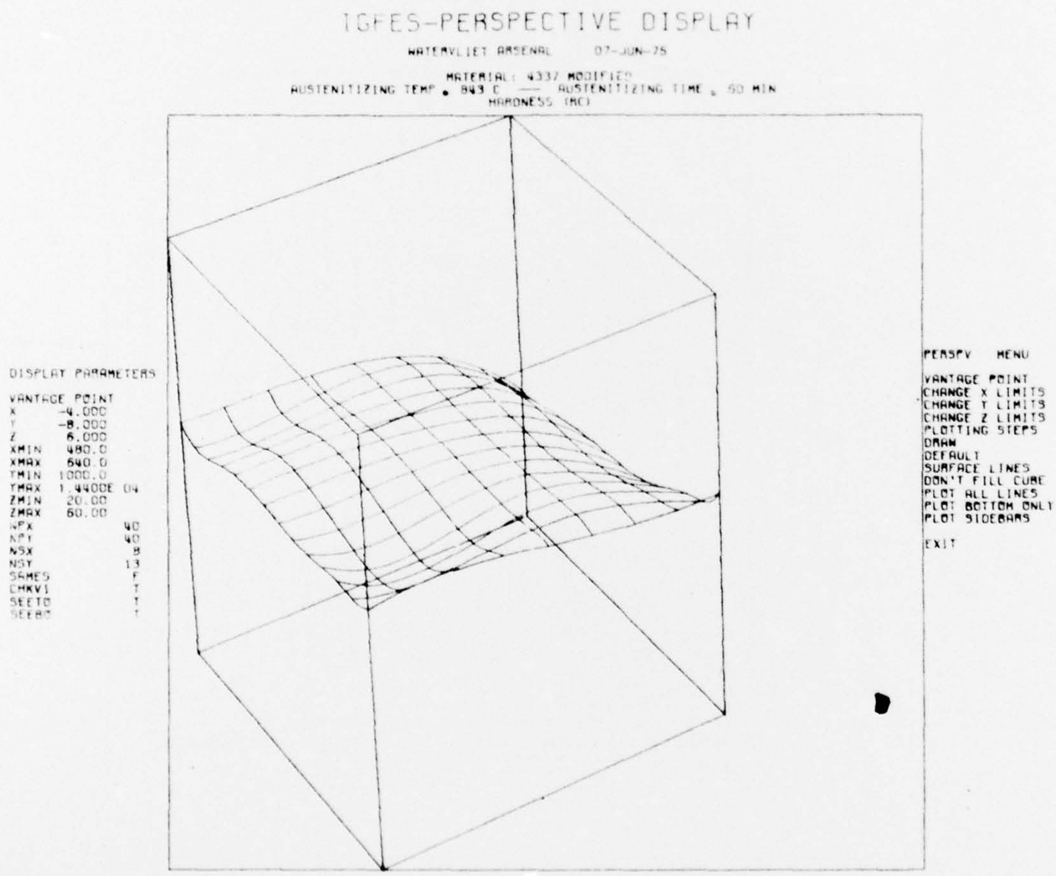

FIG. 6a Perspective plot of Hardness (R_c)

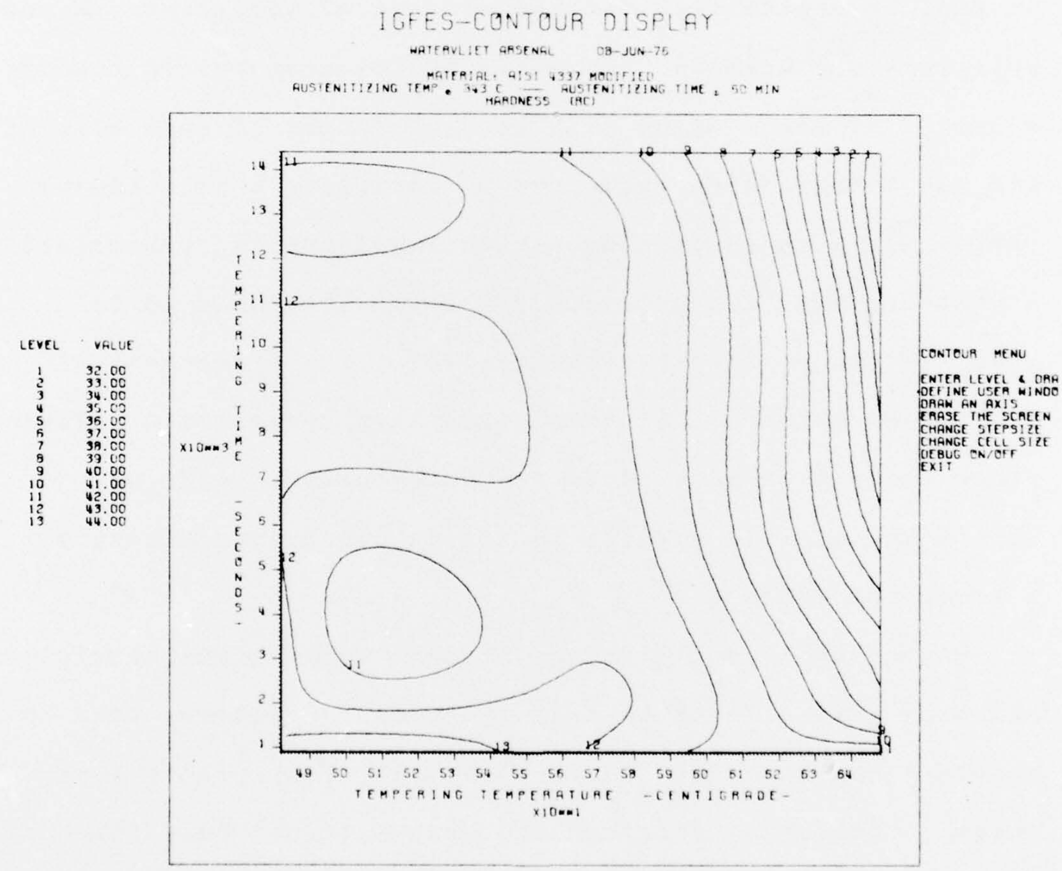

FIG. 6b Contour plot of Hardness (R_c)

An expected difficulty with this type of system is that it is useful for a particular specimen composition and thickness range. While good results (within approximately 3% of predicted values) have been obtained for other alloy compositions bordering on that used in this present investigation, it must be stated that precise effects of variations in compositions are unknown. It would be advantageous to conduct a series of tests using high and low ranges of each element, and use a regression technique to formulate a relationship useful for a range of composition and tempering parameters. A user-oriented computer program could then be used to generate the perspective and contour plots of mechanical properties expected for that particular composition. These plots could then be used to schedule furnace loads or determine possible savings in energy use by processing at a lower temperature.

A second caveat with the present work is the consideration of mass effects in heat treating. Specimens used to generate the base data were essentially flat plates 25mm thick. Commercial forgings are generally not only thicker but also of varied shape. For products such as these, a more extensive data base would be necessary to take mass effects into account, or an algorithm for estimation of

properties will be required.

CONCLUSIONS

Contour mapping of mechanical properties is a viable way of choosing tempering parameters if the restrictions of the graphics system are kept in mind.

Further work on mass and constitutional effects on mechanical properties are required before general use of such a graphics system by untrained personnel would become common.